Inventory and Monitoring Coordination

Guidelines for the Use of Aerial Photography in Monitoring

U.S. DEPARTMENT OF THE INTERIOR
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Introduction

The terms "inventory" and "monitoring" as used in this reference generally imply the application of remote sensing techniques. Remote sensing, which is the observation or measurement of an object without coming into physical contact with it, has been used for rangeland inventory and monitoring since the 1930's (Moyer, 1950). The primary sensor was, and still is, the aerial camera. Other sensors include multispectral scanners, thermal radiometers, and radar that can be operated from aircraft or satellite platforms. During 1983, a Bureau of Land Management (BLM) Rangeland Remote Sensing Task Force was formed to evaluate and recommend strategies for the application of remote sensing to rangeland monitoring needs. The task force was chaired by a representative of the Washington Office and included five or six individuals from several state offices. The group met from time to time over a period of several years, and in March 1985, issued a final report that recommended a formal evaluation of remote sensing for its applicability to rangeland monitoring.

One of the recommendations of the task force was that a selected bibliography of applications of remote sensing methodologies to rangeland inventory and monitoring be prepared. The bibliography, which reviewed 97 documents and included author abstracts and reviewer comments, has since been published and was distributed to all BLM field offices in the spring of 1986 as Technical Reference 4400-9.

Another recommendation of the task force was that the Service Center's Branch of Remote Sensing (now the Remote Sensing Section, SC-671C, of the Branch of Mapping Sciences) undertake an evaluation of remote sensing systems for their applicability to rangeland monitoring. As a result of the literature review done in compiling the above-referenced bibliography, the decision was made that the needs of the Bureau could most nearly be met using low level, large-scale, stereo aerial photography. The use of the more conventional medium and high altitude photography and satellite imagery was ruled out because these mediums lack adequate resolution and timing. At the outset, the project was envisioned as a two-phased undertaking as follows:

Phase 1. The testing, validation, and documentation of the capabilities of large-scale photography to identify and quantify traditional attributes utilized in monitoring range trends.

Phase 2. The evaluation of large-scale photography to serve as a change detection alert or "red flag" to supplement rangeland monitoring.

The subsequent studies investigated the following variables of photo acquisition and interpretation:

- Scale - Photo scales in the range of 1:300 to 1:1,500 were tested.
- Camera format - Formats of 70 mm (2.25 x 2.25 in) and 9 x 9 inches (23 x 23 cm) were utilized.
- Platform - Operations from both fixed-wing and rotary-wing (helicopter) platforms were conducted.
- Film - Both true color and color infrared films were tested.
- Environment - Work was conducted at several different sites in order to experience some of the diverse vegetation types characteristic of BLM lands.
- Navigation system - The use of Loran-C was evaluated as an aid in locating and navigating to the photo plots.
- Photointerpretation method - Several interpretation and sampling techniques were studied and utilized, including broad scale polygon type mapping, point intercept (i.e., dot-grid) interpretation, and the use of belt transects.

Objectives

The major objective of this study was to determine what information could be obtained using large-scale stereo aerial photography to alert managers to probable changes in rangeland conditions. The objective of this technical reference is to document the results of this study, to provide managers with guidelines for the acquisition of large-scale photography as well as document its application with emphasis on livestock grazing management. However, this work should also have applicability to other endeavors such as forestry, wildlife, wilderness, cultural, and mineral management. The study results should not be construed as an effort to supplant managers' needs for site visitation. Rather, a photo analysis should call managers' attention to field sites that warrant further validation of change through on-the-ground visits and assessments in order to rationalize or justify modifications in a management strategy.

Study Areas

In order to test the methodology, the study was conducted at several sites that were representative of the plant types most frequently found on BLM lands, and at sites where preexisting photography might have been available. The areas selected were in the southern California Desert, on two sites in western Colorado, and near Baker in eastern Oregon (Figure 1).

The California Desert site was in an area generally referred to as the Basin and Range Region of the Mojave Desert of southeastern California, and was representative of many of the arid public lands found in the southwestern U.S. Studies at this site utilized preexisting photography collected in the period 1978/79 in support of and prior to preparation of the California Desert Conservation Plan (McLeod and Johnson, 1980). Another set of photos from a 1985 flight was also available, thus providing multitemporal documentation. Both were acquired at a nominal scale of 1:1,000 using a large format 9- x 9-inch metric or mapping camera and true color films (Figure 2).

The two Colorado sites, located near Kremmling and Black Mesa, were chosen because ground measurements and large-scale 70-mm true color and color infrared photographs acquired in July 1968 at a scale of 1:800 were available from a previous study conducted by the U.S. Forest Service. In order to provide for multitemporal

Figure 1. Locations of study areas utilized in this project.

coverage of the Colorado sites, the photography was repeated in 1987 again in color and color infrared using 70-mm cameras. Use of a helicopter platform allowed for the acquisition of stereo photos at scales as large as 1:300 and 1:600. The Colorado sites both lay at elevations in excess of 8,000 feet (2438 m) and were characterized by mixed shrub types and grasslands intermingled with both deciduous and coniferous forests.

The Baker, Oregon site was typified by a shrub-steppe vegetation characteristic of southwestern Washington State, eastern Oregon, and parts of Idaho. The Baker site required the acquisition of new photography during 1986 (acquired in a 70-mm format using true color film). As a final test of the developed procedures, the Baker site was again photographed in 1988 using true color film and a large-format mapping camera operated in a fixed-wing aircraft equipped with a Loran-C navigational aid (Figure 3). Table 1 summarizes the variables studied at each of the four sites.

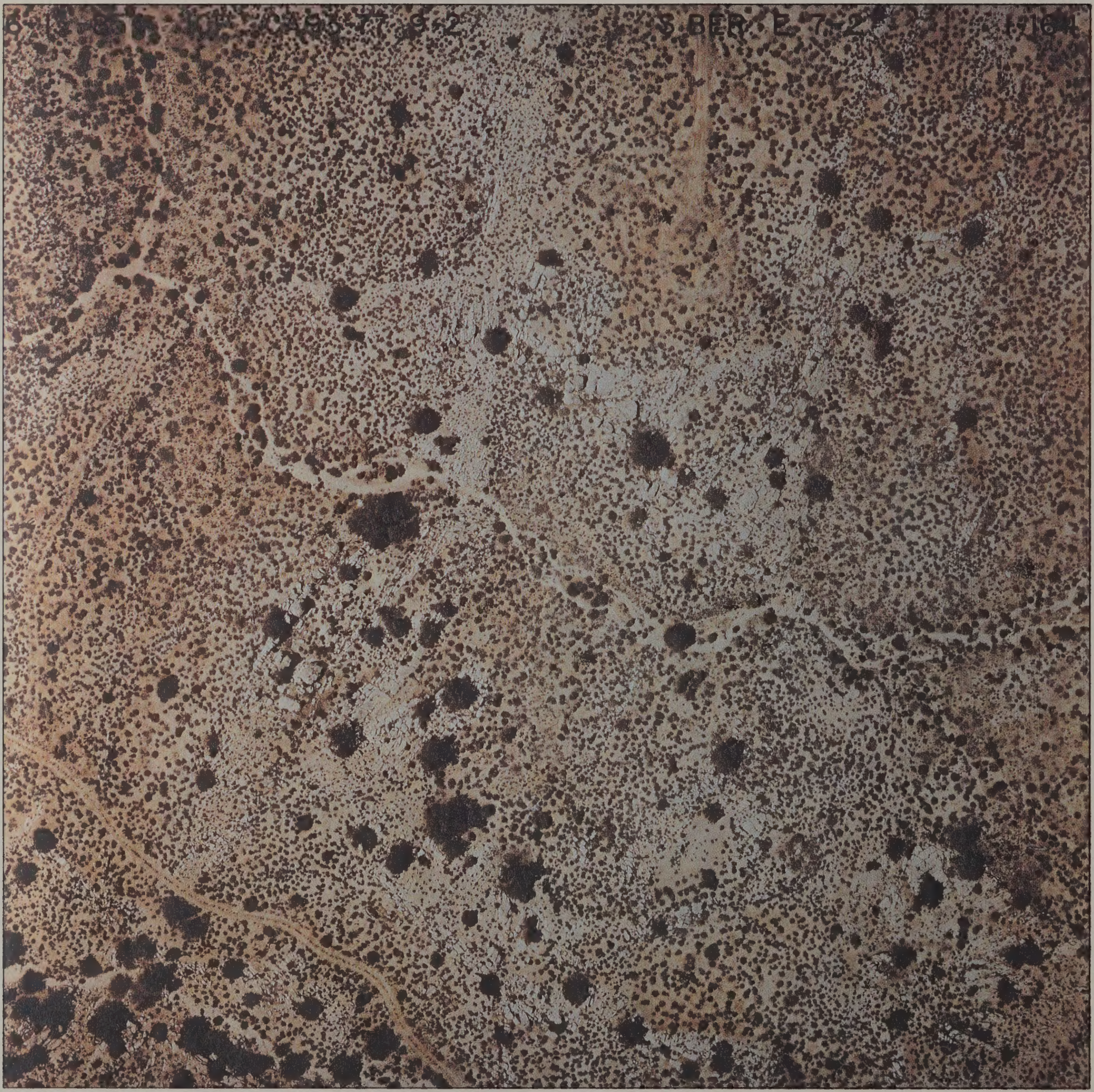

Figure 2. Example of a single frame of California Desert large-scale aerial photography. The print shown was reduced for this publication to approximately 78 percent its original size. The original film scale was 1:1,125. The most abundant shrub encountered during a ground visit to this site was cheesebush (*Hymenoclea salsola*) with approximately 60 percent of the surface being bare soil and rock.

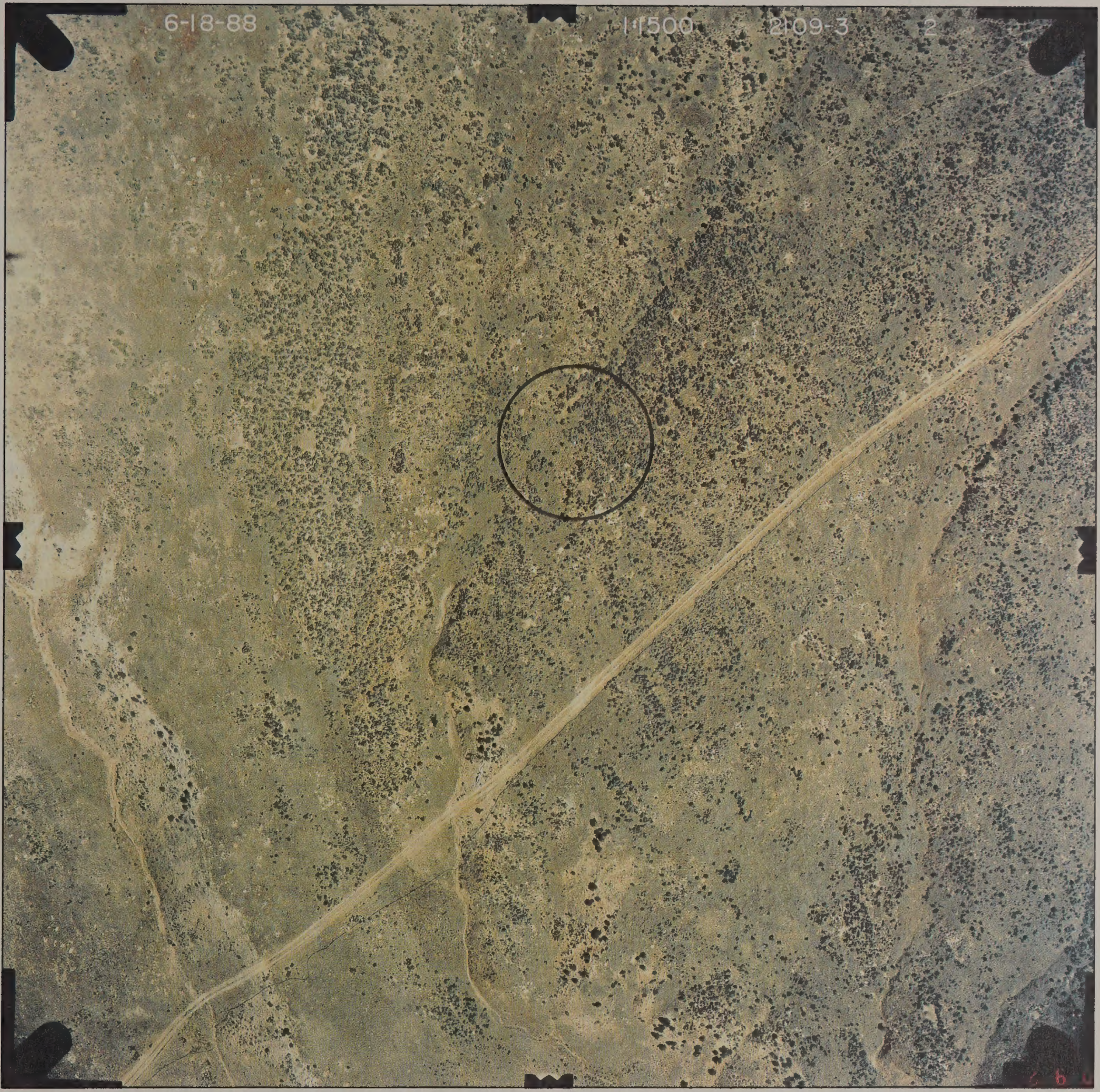

Figure 3. Example of a single frame of large-scale aerial photography from the Baker, Oregon Resource Area. The print shown was reduced for this publication to approximately 78 percent its original size. The example is a 1:1,500 scale true color print of one of the rangeland monitoring study plots. The vegetation on the circular plot is a shrub-steppe type consisting primarily of big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus spp*), and perennial grasses. There are scattered patches of annual grasses present.

Table 1. Summary of Aerial Photo Acquisition Parameters

Site	Date	Camera Format	Scale	Film *	Aircraft Platform	Navigation Aid
Kremmling, CO	1968	70 mm	1:800	C, CIR	Fixed Wing	
Black Mesa, CO	1968	70 mm	1:800	C, CIR	Fixed Wing	
CA Desert	1978/79	9″x9″	1:1,000	C	Fixed Wing	
CA Desert	1985	9″x9″	1:1,000	C	Fixed Wing	
Baker, OR	1986	70 mm	1:500 1:1,200	C	Fixed Wing	
Kremmling, CO	1987	70 mm	1:300 1:600	C, CIR	Rotary Wing	
Black Mesa, CO	1987	70 mm	1:300 1:600	C, CIR	Rotary Wing	
Baker, OR	1988	9″x9″	1:1,500	C	Fixed Wing	Loran C

* C = True Color
CIR = Color Infrared

Study Methods and Procedures

When the study was initiated, the objectives were to detect, identify, and monitor rangeland vegetation at the species level. As the study progressed, it became readily apparent that it was not possible to identify and monitor species of grasses and forbs. Therefore, the techniques used to collect and interpret the photographs evolved over time. The aerial photo scales, formats, platforms, film types, plot shapes and sizes, and photointerpretation methods changed as new knowledge was gained.

The rangeland monitoring plots were photographed with large (1:1,000 and smaller) and very large (greater than 1:1,000) scales that were as large as 1:300. The goal was to use the smallest possible scale that could identify general categories needed to monitor rangeland trend. In 1986, the photo scales tested were 1:500, 1:1,000 and 1:1,200. A final attempt was made in 1987 to identify and monitor herbaceous vegetation using scales of 1:300 and 1:600. Neither proved fully successful; the conclusions from these studies were that many species of grasses and forbs could not be accurately identified even at these large scales.

As a test of the methodology, 1:1,500 scale photographs were acquired in 1988 at the Baker, Oregon site to map broad vegetation cover groups (i.e., annual and perennial grasses, shrubs, bare soil, and rock). Most of the large-format aerial photography used in this study was acquired with cameras that had 6-inch (15-cm) focal-length lenses, the exceptions being 8.25-inch (21-cm) and 12-inch (30-cm) focal-length lenses that were used to obtain the 1:1,000 scale photographs in California. The acquisition of large-scale stereo photography requires that aircraft be operated at low altitudes and slow forward speeds, which contradicts the rules of flight safety. Longer focal-length lenses were used in order to increase flight altitudes and thus improve the safety margin.

Film format and photo scale must be carefully considered when trying to obtain overlapping photographs for stereo viewing. All scales larger than 1:1,000 were obtained with small format 70-mm cameras, because large format cameras do not cycle fast enough to permit adequate stereo overlap at the larger scales. The 1:500 scale photographs were obtained with 70-mm fast recycling cameras (5-6 frames per second). The 1:300 and 1:600 scale photos were also obtained with 70-mm cameras operated from a helicopter platform that did not have a forward speed greater than 10 mph (16 kmph). Large format 9-x 9-inch cameras were used to acquire the 1:1,000 and 1:1,500 scale aerial photographs. Large format photography covers a larger area of land surface and provides the photointerpreter with more reference points for geographic orientation than a smaller format camera operated at the same altitude and with the same focal length lens. Large format photography also allows the aircraft pilot greater navigational latitude for repeat photography of an established plot.

A Cessna[1] 185 and 206 were the predominant camera platforms used for the large- and very large-scale photography. A Bell 47 Soloy helicopter was used to obtain the 1:300 and 1:600 scales with flying heights of 150 feet (46 m) and 300 feet (91 m) above ground, respectively. Helicopters were more maneuverable and could hover or move slowly over the plots. They were safer at lower altitudes and slower flying speeds, but their hourly charge of $450 was approximately three times higher than for a fixed-wing aircraft.

Both true color and color infrared films were tested. Plant species differentiation may be better when color infrared film is used. When dual cameras were available, both film types were exposed. The true color films included Kodak SO-397, Kodak Aerocolor Negative 2445, Kodak Aerochrome MS 2448, and Kodak Ektachrome 64. The color infrared film used in all tests was Kodak Aerochrome Infrared 2443.

In an attempt to reduce the time spent circling and looking for an established plot, a Loran-C navigation system was tested at the Baker site in the last year (1988) of the study. Loran is a navigational system used primarily by ships and planes. The system uses low frequency radio signals from a master station and at least one secondary station to fix position. The system is land based. Loran has been in use since World War II and most of the stations were established in U.S. coastal areas. Therefore, the accuracy of the system is dependent upon distance from these coastal stations. In these studies, latitude and longitude coordinates of fixed-plot centers were recorded on the ground with a Loran-C unit, and the same unit was used in fixed-wing aircraft to navigate to the general vicinity of the plot. Final adjustments were then made visually to line up on the plot markers.

Photointerpretation methods and vegetation monitoring parameters changed and evolved during the study.

[1] *Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.*

Initially an attempt was made to measure frequency, density, and canopy cover of shrubs, grasses, and forbs. Findings were that frequency and density could not be measured accurately and consistently with large-scale aerial photography. However, canopy cover could be determined with aerial photography. In the California Desert site, cover alone was determined using point intercept samples at fixed intervals along transect lines. And finally, in the last year of the study (Baker, Oregon), cover was delineated into polygons throughout each plot.

Results and Discussion

Based on the 3-year monitoring study, which included the testing of photo scales, film formats, camera platforms, sample plot sizes and shapes, and photointerpretation methods, the following findings evolved:

Scale

Rangeland monitoring plots were photographed at scales of 1:300, 1:500, 1:600, 1:1,000, 1:1,200, and 1:1,500. These scales represented the range of very large- to large-scale aerial photography. Very large-scale is here defined as those scales from 1:1,000 and larger, or for the study cited herein, those scales in the range 1:1,000 to 1:300. Large-scale aerial photography is defined as that photography having scales in the range 1:1,000 to 1:12,000. More image detail could be seen on large-scale as opposed to medium-and small-scale photographs, but the field of view or image area was smaller. When the camera focal length remained the same, a larger scale meant the aircraft platform was flown closer to the ground. For example, with a 6-inch focal length camera lens, at 1:300 and 1:1,500 scale, the aircraft was 150 feet (45.7 m) and 750 feet (229 m) above the ground, respectively. However, for the 1:1,500 scale, flying heights of 1,030 feet (314 m) and 1,500 feet (457 m) would be possible with 8.25- and 12-inch focal length lenses, respectively. Scales larger than 1:300 were not tested because both helicopters and especially fix-winged aircraft would be operating at unsafe altitudes.

At first, the goal was to see if species of shrubs, grasses, and forbs could be identified. Preliminary results showed that most species of grasses and forbs could not be accurately identified, even at the 1:300 scale. However, large leaf forbs such as arrowleaf balsamroot (*Balsamorhiza sagittata*) and plants in bloom at the time of overflight could be identified at the 1:300 to 1:600 scale range. For example, since thick patches of lupine (*Lupinus ammophilus*) were identifiable, it is highly likely that invasions of noxious weeds, such as leafy spurge (*Euphorbia esula*) and knapweed (*Centaurea spp.*), could be monitored. Since the BLM Oregon rangeland professionals decided that for monitoring they only needed the delineation of broad categories, the decision was made to only identify and monitor shrubs, annual and perennial grasses, bare soil, and rock. The percent increase or decrease of shrubs, perennial grasses, and bare soil would serve as an indicator or flag that closer field examination was necessary. The validity of recording only broad categories of plant types was confirmed by a subsequent aerial photography range study conducted in southwestern Arizona (Knapp et al., 1990) in which vegetation was characterized as either a tree, shrub, or cactus.

A general rule in aerial photography is to use the smallest scale possible that will provide the desired level of detail. In this way a larger area is photographed and the cost of acquisition, interpretation, and analysis of aerial photography is minimized. For example, at a scale of 1:300, a single 9- x 9-inch photograph covers 1.16 acres (0.47 ha), but a 1:1,500 scale photograph covers 29.05 acres (11.76 ha). The cost of a 1:300 scale photo is four times the cost of the 1:1,500 scale photo if the same land area is photographed. A test of 1:1,500 scale showed that the broad categories previously mentioned could be detected and identified.

Based on the level of detail needed and cost minimization, the recommended scale range for rangeland monitoring would be 1:1,000 to 1:1,500. Scales smaller than 1:1,500 were not adequate to monitor the desired classes.

Camera Format

Camera format relates to the dimensions or size of the original film exposed in a camera. Formats tested during the study included 70-mm and 9-x 9-inch. If camera focal length and flying height are kept constant, a single frame of small format film covers less ground area than large format film.

The rangeland monitoring plots were not photographed with 35-mm (0.9- x 1.42-in) format cameras. Presently, 35-mm large-scale photography is not feasible for rangeland monitoring. Granted, 35-mm photography is cheaper than 9- x 9-inch, because film and processing costs and the initial equipment investment are less. Also, an aircraft would not require a belly port because side mounts are available or could be made for high-wing aircraft (Cosgriffe et al., 1973). However, the field of view of small format 35-mm large-scale aerial photography is very limited, and a pilot's ability to accurately overfly and photograph established sample plots would be severely tested. The largest circular plot that could be photographed is 0.23 acre (0.092 ha) at a 1:1,500 scale.

Additionally, the photointerpreter would have very few recognizable reference points. For those that would like to try to use 35-mm aerial photography, the publication by Meyer et al. (1978) is recommended. This publication has a "how to" section and good tables relating scales and lenses, etc.

In addition, 70-mm photography is not recommended for rangeland monitoring at this time. Film purchase and processing are more expensive than 35-mm and an aircraft with a camera port is usually required. Acquisition of 70-mm photography is not as readily contracted because fewer photo contractors have 70-mm equipment. The field of view is larger than 35-mm and circular plots that are 1.42 acre (0.57 ha) or less can be photographed at a 1:1,500 scale. Since 70-mm cameras cycle film faster than 9-x 9-inch cameras, 60 percent endlap can be obtained with aircraft speeds of 76 mph (123 kmph)[2] or less. Readers are referred to Ulliman et al. (1970) for a publication that describes 70-mm aerial photography.

A large format, 9-x 9-inch camera is recommended because the photointerpreter has more geographical reference points, it provides flexibility for increasing plot size, and it permits a modest navigational error in overflying the plot. The recommended scale range can be acquired with the slower cycling large format cameras, provided the camera platform is operated at a ground speed of 76 mph[3] or less. In addition, the cost may go down due to increased competition because most photo contractors have large format mapping cameras.

When a large format (9- x 9-inch) mapping camera is used for large-scale aerial photography, it is recommended that it have Forward Motion Compensation (FMC). Aerial photographs taken 750 feet above the ground have a higher chance of image blur compared to those taken at higher flying altitudes. FMC reduces image blur due to the forward motion of the aircraft. The result is photographs with sharp, crisp detail.

Platform

The camera platform can be either a tethered balloon (Whittlesey, 1970; Witherspoon et al., 1990), helicopter, or fixed-wing aircraft. Balloons are not practical because they only allow for a small number of plots to be photographed in a day, they are limited by wind, and they can only accommodate a platform for 70-mm or smaller cameras. With the large number and wide distribution of rangeland monitoring plots, balloons would be less efficient and more expensive than other alternatives. The following discussion will thus emphasize the differences between helicopter and fixed-wing aircraft.

Helicopters can fly safely at slower speeds and can land and wait until conditions are favorable. Helicopters can either hover or fly 10-20 mph (16-32 kmph) over plots. However, they are not a stable enough platform for large format cameras, not many photo contractors have them, and the hourly charge for helicopter and pilot is higher than fixed-wing aircraft (see Table 2). Vibrations of the helicopter frame can be transmitted to the camera and mount, which can result in image blur. Attempts have been made to dampen these vibrations, but the modifications are costly and do not always work. In addition, it is not always practical to cut a port in a helicopter for a 9-x 9-inch camera and its mount.

Fixed-wing aircraft, on the other hand, provide a more stable platform, more photo contractors have them, and the hourly cost is much lower. Fixed-wing aircraft do not vibrate like helicopters and small vibrations can be

Table 2. Costs of Acquistion of Aerial Photography

Location/Year	Platform	Film/Format	Cost/Plot ($)
California/1986	Fixed Wing	True Color/9x9 inch	98
Oregon/1986	Fixed Wing	True Color/70 mm	517
Colorado/1987	Rotary Wing	True Color & CIR/70 mm	1,041
Oregon/1988	Fixed Wing	True Color/9x9 inch	259
Oregon/1989	Fixed Wing	True Color/9x9 inch	291

[2] *Assumes a photo scale of 1:1,500 and a film cycle rate of 1 frame per second.*
[3] *Assumes a photo scale of 1:1,500 and a film cycle rate of 0.25 frame per second.*

dampened by the camera mount. Many photo contractors throughout the western U.S. have aircraft with a camera port for large format cameras. Aircraft such as Cessna 170s and 180s can safely fly 76 mph or less, the speeds required to obtain 60 percent photo stereo overlap. Cessna 206s and 210s may require a Short Takeoff and Landing (STOL) kit to fly the required speed. The hourly charge for a fixed-wing aircraft is between $120-$160 per hour, which can be one third the cost of a helicopter. The recommendation is that a fixed-wing aircraft be used to acquire the recommended photo scale and film format.

Film

During the 3-year study, color infrared (Kodak Aerochrome Infrared 2443) and true color Kodak SO-397, Kodak Aerocolor Negative 2445, Kodak Aerochrome MS 2448, and Kodak Ektachrome 64 films were used. The true color and color infrared films were used separately or simultaneously. If only one film type is used, true color film is recommended because it is easier to get a correct exposure, more photo contractors have experience with it, many photointerpreters prefer it, and in this study, there was no statistical difference in photointerpretation accuracy between true color and color infrared film. Color infrared film has a narrow latitude of exposure and a one-half f-stop can make the difference between success or failure. Color infrared is even more unforgiving if handling and storage is not done according to manufacturer's specifications. Also, because film batches often vary more than with true color, it is not easy to say a real change has occurred when photos taken with different film batches are compared. Another disadvantage with color infrared film is the loss of detail in shadows. It is even harder to justify use of color infrared film in a sparse-vegetation environment like a desert.

Although color infrared has better haze penetrating capabilities than true color film, at the low flying heights of 500 to 750 feet above terrain, the haze penetrating capability is not a critical factor. With medium and small scale photography collected from higher altitudes, this would be an important consideration.

When true color film is used, it is recommended that photography be taken at the proper stage of vegetation development. For example, we recommend that color photography be taken during the time when annual grasses are senescent, and hence there is maximum color contrast between annual and perennial grasses.

The film products that were used for photointerpretation were mostly paper prints. It is recognized that positive transparencies are better for interpretation because film acutance is better. Photo images appear sharper and clearer. Field offices should have the necessary light table and stereoscope if film transparencies are to be viewed and interpreted.

Photointerpretation Method

Attempts were made to determine frequency, density, and canopy cover of shrubs, grasses, and forbs. Our preliminary results based on corroborating ground observations clearly indicated that frequency and density could not be reliably determined with very large- or large-scale aerial photography. This was especially true for grasses and forbs at the species level. Canopy cover could, however, be mapped and monitored for the more general categories of shrubs, grasses, and forbs. The recommended photointerpretation method of determining canopy cover will vary depending on the type of environment.

Arid Environment

In arid environments (less than 10 inches or 25.4 cm annual precipitation), where the vegetation canopy is not contiguous, such as situations where plant canopies form aggregates or clumps, mapping of the vegetation cover into polygons is not appropriate. It could result in a myriad of individual polygons or in the inclusion of large amounts of bare ground between each assemblage of plants. In such a situation, point intercept sampling is preferred. In their study in southwestern Arizona, Knapp et al. (1990) utilized a dot grid with a minimum of 200 points recorded. For the study in the California Desert prior to the preparation of that reference, photointerpretation points systematically located along linear transects were used. This was accomplished by placing a transparent plastic overlay with a grid pattern over the photo (Figure 4). This overlay was composed of five transects each containing 20 index points along the length of each transect. At a photo scale of 1:1,000, each transect was equal to a ground distance of 197 feet (60 m) with a spacing between transects of 33 feet (10 m). A rectangular plot was utilized in this case to facilitate establishment of the ground plot that was used to corroborate the photo measurements.

Semiarid Environment

For definition purposes, semiarid environments receive less than 20 inches (50.8 cm) and greater than 10 inches of annual precipitation. Modified Daubenmire plot (Bureau of Land Management, 1985) and line intercept methods (Canfield, 1941) were used initially to photointerpret canopy cover. There was difficulty in interpreting canopy cover with the modified Daubenmire microplots positioned at equidistant points along transect lines. The plots were just too small to make an accurate determination of percent canopy cover. The line intercept method was not very successful either because it was extremely difficult to reposition the transect lines in the same position for two different photography dates. A better approach was to map the canopy cover of shrubs, annual and perennial grasses, bare soil, and rock by drawing polygons around each of the surface classes. The polygons in the rangeland monitoring plots were then digitized and entered into a geographic information system. The same procedure was repeated when the plots were rephotographed. In this way, the percent increase or decrease of shrubs, perennial grasses, and bare soil could be easily determined.

The key to ensuring consistent photointerpretation results, even for different interpreters, is to clearly define the classes of interest and set a minimum mapping unit.

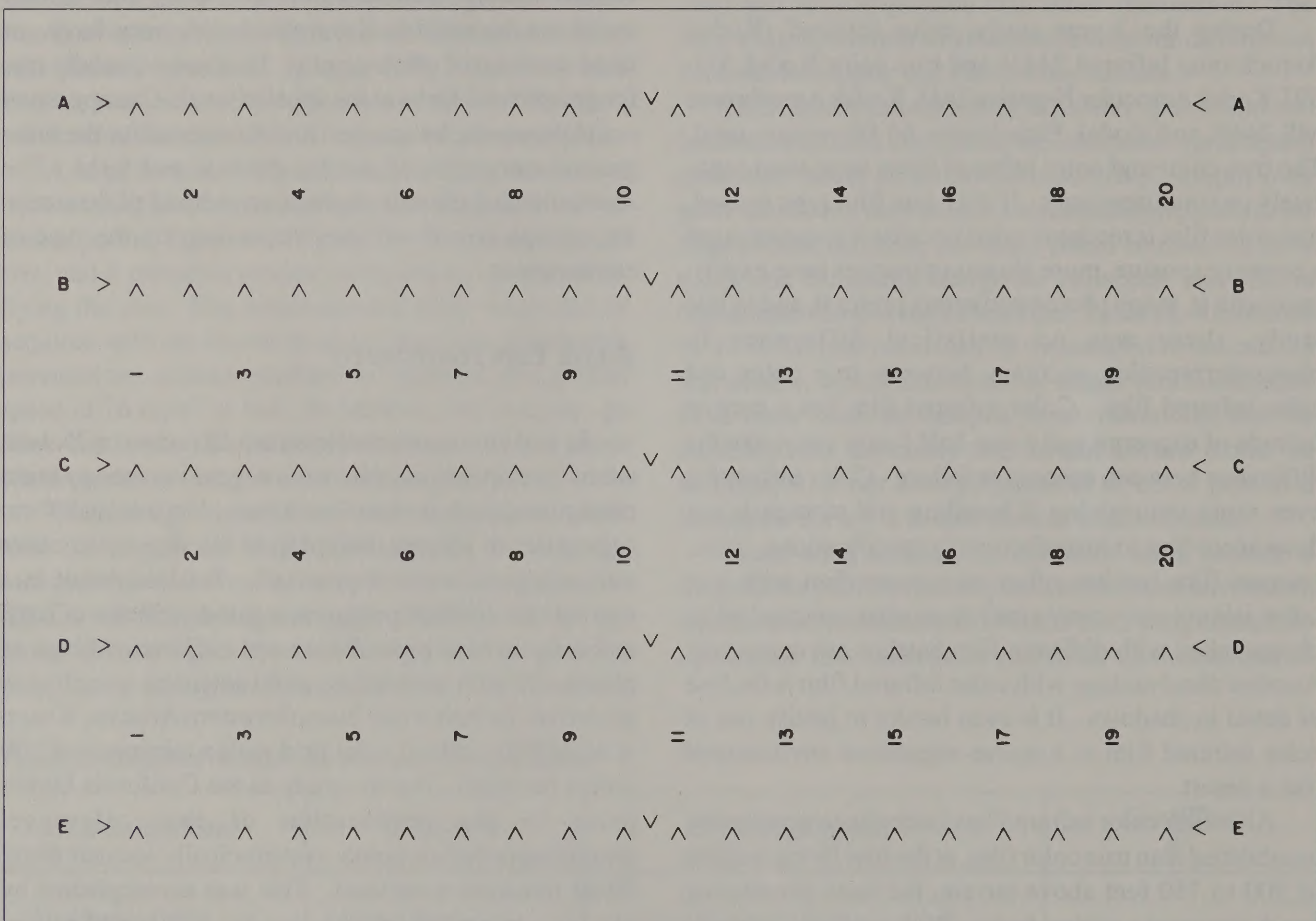

Figure 4. Overlay grid used for the photointerpretation of California Desert film. (Enlarged 2-1/2 times actual size.) The horizontal pointing arrows indicate the end points of each of five transects comprising the sample plot. The downward pointing arrows indicate the midpoints of the respective transect. The interpreter identified the feature that occurred at the tip of each upward pointing arrow.

The minimum mapping unit is the smallest polygon drawn around a cover class at a given scale. The smallest polygon has to be big enough so a label can be placed inside it. For example, at a 1:1,500 scale, the smallest photo and ground polygon could be 0.22 inch (0.56 cm) and 27.5 feet (8.4 m) in diameter, respectively.

Plot Shape and Size

Plots of various shapes and sizes were used during the 3-year study. Again, as with the photointerpretation method, the recommended plot shape and size varied with the type of vegetation environment (i.e., arid or semiarid).

Arid Environment

As reported above, the plot size and shape used in the California Desert site was a rectangular area approximately 0.7 acre (0.3 ha). In contrast, Rowlands (1978) had determined that the overstory of upland Mojave Desert vegetation could be adequately sampled by plots which were 0.2-2.5 acres (0.1-1.0 ha) or more in size. His minimum sampling area increased as the density of overstory plants, usually Joshua-tree (*Yucca brevifolia*), juniper (*Juniperus spp.*), and pinon pine (*Pinus monophylla*), decreased. The 100 sample points of the current study proved to be an adequate number where species diversity was not great; however, in the more common situation of many plant species, a doubling of the sampling points would have provided more accurate results. Thus, the recommendation for arid environments, such as the desert southwest, is that sample plots should be 1.2 acres (0.5 ha) or larger containing a minimum of 200 sample points. Furthermore, the photointerpretation at each of these points is best accomplished using stereo imagery viewed under a magnification of as great as 10x. In this case, it is felt the plot shape is relatively insignificant as long as the number of sample points within the plot is sufficient. A rectangular plot was utilized in the California study in order to facilitate correlations between photo sampling and coordinated ground observations.

Semiarid Environment

Rectangular plots that were 0.06 acre (0.02 ha) and square plots that were 0.01 acre (0.004 ha) in size were tried. The major problem with rectangular and square plots was the time required to mark the plot corners (on-site time during ground correlation studies). Two days were required on-site to mark the plot corners of 7 square plots. The 25- x 100-foot (8- x 31-m) rectangular plots were large enough to monitor change, but the small 19- x 19-foot (6- x 6-m) square plots were not. Rangeland monitoring plots should be from 0.1 acre (0.04 ha) to 0.5 acre (0.2 ha) to adequately monitor change in percent cover (ECON, 1987).

Circular plots are more economical to establish and maintain because only the plot center has to be marked. This can be easily done by anchoring an old rubber tire at the plot center. The sidewall should be painted white so the plot center is not confused with another anchored tire that is used to determine actual photo scale. The other rubber tire should be placed a known distance and cardinal direction from the plot center tire, for example, a tire placed 50 feet (15 m) due North of the plot center. A circular plot that is 0.4 acre (0.16 ha) with a 74.5-foot (22.7-m) radius was found to be large enough to monitor trend.

Navigation System

Loran-C navigation was used to guide the pilot into the general vicinity of the Oregon plots until such time that he could make visual recognition of the plot center. This method reduced the amount of circling required to find a plot prior to acquiring three overlapping exposures of each plot. The latitude and longitude of each plot center was determined in the field with a Loran-C unit. This same Loran-C unit was used in the airplane to guide the pilot into the general plot vicinity. For most of the Oregon plots, the pilot was able to fly to within visual sighting range of the center plot tire using the Loran-C system.

Because Loran was designed primarily for maritime purposes, it is most effective on the high seas and near coastal areas. Its accuracy is dependent upon distance from coastal transmitting stations. There are no stations in the mid-continent area, and in these situations, accuracy cannot be measured in feet — it must be measured in miles. There are, however, plans in the near future to establish Loran-C stations in the mid-continent area.

Another navigation system that could improve the navigating accuracy to fixed plots is the Global Positioning System (GPS). GPS is a system in which a receiving unit picks up signals from at least two satellites to determine its location in the two dimensions of latitude and longitude. Accuracies as high as 82 feet (25 m) have been obtained with one receiving unit taking a single reading. Because GPS was developed and is used by the military, the Department of Defense can turn on selective

availability and degrade the accuracy to 100 meters for one receiving unit recording a single value. Currently the window for receiving satellite signals in two dimensions is 22 hours during a 24-hour day because only 15 satellites are in orbit. Satellite signals will be available 24 hours a day when the full constellation of 24 satellites are in orbit (anticipated by 1992).

Cost of a GPS receiving unit is also limiting its use. Currently, a handheld receiving unit can be purchased for $3,000 to $14,000. The $3,000 unit is single channel and does not have a recorder and other features. When a multiple channel unit with recorder is available for $2,000, GPS will become an economical alternative.

Summary of Recommendations

Large-scale aerial photography can potentially supplement and improve the efficiency of rangeland monitoring. The following parameters and conditions should be considered when planning for such photography:

1. Level of vegetation and surface cover detail - Rather than trying to detect and identify species of plants, broad groupings or categories such as shrubs, annual and perennial grasses, bare soil, and rock should be monitored. Some range managers believe that monitoring the percent increase or decrease of these classes is sufficient to signal a significant change, at which time plots should be field evaluated.

2. Type of environment - Complex environments such as mountain meadows that have many plants with overlapping crowns may not be successfully monitored with aerial photographs. Aerial photography should be considered in less complex environments such as arid and semiarid areas.

3. Scales - To reduce costs, minimize image motion or film blur, and yet accurately monitor the categories in item number 1, the recommendation is that photo scales between 1:1,000 to 1:1,500 be used.

4. Formats - Large format 9- x 9-inch photography is recommended over 70-mm and 35-mm because of the greater area of coverage. Large format cameras do not cycle film as fast as smaller format cameras, but good stereo coverage can be obtained if the aircraft ground speed is 76 mph or less.

5. Platforms - Fixed-wing aircraft are recommended because they are more economical than helicopters, they are a more stable platform for 9- x 9-inch cameras, and a greater number of commercial operators are potentially available.

6. Film - True color film is recommended over color infrared because of the better resolution, reduced risk of improper exposure, and more natural vegetation appearance. However, it is critical that the vegetation be photographed during the phenological period when annual and perennial grasses can be separated.

7. Plot shape and size - In arid environments, circular plots that are a minimum of 1.2 acres (0.5 ha) in size are recommended. Circular plots that are 0.4 acre in size are recommended for semiarid areas. The plot center for the circular plot should be marked with a rubber tire that is anchored permanently into the ground. The sidewall should be painted white to distinguish it from another anchored rubber tire that is a specified distance in a cardinal direction from the plot center. The two rubber tires are used to determine actual photo scale and orientation of the plot.

8. Photointerpretation method - The use of line intercept sampling within a rangeland plot is not recommended. In arid areas of sparse or interrupted vegetation cover, point sampling is preferred. The ability to correctly relocate line transects for two different time periods is very difficult. In areas of continuous vegetation cover it is recommended that the categories in item number 1 be manually delineated into polygons. The results of the polygon mapping may then be digitized and entered into a GIS. When the plots are rephotographed at a later date, the above procedure should be repeated so the percent increase or decrease in the polygons by type can be quickly calculated with the GIS. It is also recommended that the photointerpreters receive 2 to 3 days training on basic fundamentals of photointerpretation and that they be thoroughly familiar with the local vegetation. This training should include a field visit to correlate between the training photos and the ground.

9. Navigation system - The use of a GPS navigation system is recommended at such time as there is a full complement of satellites and the cost of the receiving units is $2000 or less. In the interim, Loran-C navigation could be used near coastal areas, and when the mid-continent stations are operational, at interior areas. If Loran-C navigation is used, it is strongly recommended that the plot centers be carefully plotted on large-scale topographic maps. The topographic maps will provide additional help to the pilot in locating plot centers and some photo contractors will require them.

Rangeland monitoring with large-scale aerial photography will never replace conventional field monitoring. It might best serve as a "red flag" to attract the attention of a range manager in the case of an inordinate or unexpected change in range condition, at which time further validation of the change should be carried out through on-the-ground inspection. Reduced personnel and budgets now and in the foreseeable future warrant consideration of large-scale aerial photography. Using the above recommendations as guidelines, it is believed that large-scale aerial photography can be an effective monitoring tool for the rangeland manager.

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Appendix I
Example of Contract Specifications for Procurement of Large-Scale Photography

For those who would like to contract for the acquisition of large-scale aerial photography, the following example is included in this technical reference. These specifications pertain to photography contracted for and collected within BLM's Taos Resource Area of New Mexico in 1981 and any reference to that project is for illustrative purposes only. It will be necessary to tailor these specifications to the reader's area of interest and specific requirements. This example is preceded by a specification data sheet which is universally used by BLM's Service Center for the specification of aerial photography and is followed by the detailed specifications which would ordinarily comprise Section C of a standard solicitation. If any assistance is required by BLM offices in implementing these specifications, the Service Center's Remote Sensing Section should be contacted.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

SPECIFICATION DETAIL SHEET

Solicitation Number

Project Name and/or Number

Taos Resource Area Remote Sensing Project

LOCATION

State	District	Symbol	Square Miles	Linear Miles
New Mexico	Albuquerque		Approx. 200 Sample Unit Sites	N/A

DATES PHOTOGRAPHY MAY BE TAKEN		AERIAL CAMERA	
Starting	Completion	Focal Length	Lens Type
May 10, 1981	May 31, 1981	per specifications attached	per specifications attached

Time of day photographs may be exposed:

FLIGHT INFORMATION		TYPE		
Above mean sea level		Film to be used	Photographic prints	Number of each print
Above mean terrain		Aerochrome MS 2448 or Ektachrome Aerographic SO 397		
Scale of photography	1:1200 to 1:1500			
Flight direction	N - S or S - N			

INDEX not required

☐ Photo Index ☐ Spot Index	Type of material	Number Required
Index Scale:		

PHOTOGRAPHY SPACING REQUIREMENTS

☐ B/H W/H decimal ratio	CHECK METHOD USED			☐ Percentage overlap
	Min.	Av.	Max.	
Base height ratio along lines of flight (endlap)	52%	60%	67%	Endlap (overlap in line of flight)
Width height ratio between flight lines (sidelap)				Sidelap (overlap between adjacent flight lines)

Special requirements:

This procurement requires that vertical aerial photography be acquired at each of 200 randomly sited sample plots with complete stereo coverage of each plot. All sample unit plots will be 149 feet in diameter and will be marked by a rubber tire with white sidewall located at plot center. The location of each sample plot will be specified by the BLM on the largest scale USGS quad map available (either 1:24000 or 1:62500).

All sample unit plots, basic quantity plus any option quantity, shall be within the project area which is delineated on the attached map (Attachment No. 1).

The initial estimate is for the photographing of 200 sample unit plots with the option to increase by 100 the plots to be photographed.

Description/Specifications

A. Background

The Bureau of Land Management (BLM), in the course of conducting a survey of rangeland features within the Albuquerque District of New Mexico, requires large-scale vertical aerial photography of randomly selected sample units. The resulting photography is to be interpreted by BLM in order to assess plant and surface material composition by type and condition. The photography called for in this specification will be of sample units 149 feet in diameter randomly sited on BLM-administered and state and private lands. Excluded lands will be Indian reservations, national forests, national parks and monuments, military and national security sites, and land grants. With these exceptions, the sample units to be photographed will be located within two land parcels as shown in Attachment 1. The larger parcel, comprised of approximately 5.3 million acres, consists of that part of Rio Arriba County east of the 107° W. meridian of longitude and Los Alamos, Santa Fe, and Taos Counties in their entireties. The greatest concentration of BLM, state, and private rangelands in this parcel are in the Cebolla area of Rio Arriba County and along the Rio Grande Valley. The second parcel, located in central San Miguel County, encompasses an area approximately 500,000 acres in size.

B. Materials and Labor

The Contractor shall furnish all labor, equipment, transportation, materials, and supervision. He shall execute and finish all aerial photography for the Bureau of Land Management project named and described in the Specification Detail Sheet.

C. Cameras

1. Type

   a. A single-lens precision-type aerial mapping camera shall be used to expose film on a format approximately 9 x 9 inches.

   b. The camera shall be equipped with an approved means of flattening the film at the instant of exposure.

   c. The fiducials shall be capable of registering clear, well-defined fiducial marks on the film.

   d. The camera shall be equipped with a between-the-lens shutter of the variable speed type.

   e. The camera shall be equipped with marks that will record the camera number, calibrated focal length of the lens, and level bubble on each exposure on the inside of the focal plane frame or on a data strip between frames.

   f. The camera shall be equipped with a lens with a focal length appropriate for obtaining a film exposure within the desired range of specified scales and commensurate with safe and acceptable flying altitudes. The lens shall have an Area Weighted Average Resolution of 80 line pairs/mm or better as verified by a lens test or calibration report which shall be provided.

   g. An antivignetting-type filter shall be used. All filters shall have two surfaces parallel to within 10 seconds of arc. Optical quality shall not cause undesirable reduction in image resolution (gelatin filters are not acceptable).

   (Special care shall be taken to assure that the antivignetting pattern will be such that the density will be uniform from the corners through the center of the image.)

   h. Appropriate glass filter combinations shall be used to achieve proper tonal rendition of the project area. See the Specification Detail Sheet for requirements.

   i. The platen shall not depart from a true plane by more than 0.013 mm.

   j. The angle between the lines joining opposite members of two pairs of fiducial marks shall be 90° plus or minus 1 minute, and the intersection of the lines shall indicate the position of the principal point within plus or minus 0.03 mm.

k. In addition to the above, the Contractor shall make every effort to minimize image motion to the extent that terrain features (shrubs, rocks, trees, etc.) can be interpreted from the original film. In no case shall the image motion within the central 3-inch diameter of the exposed film exceed 50 micrometers.

D. Film

1. Type and Handling - Aerial Film

a. Only unexpired, dimensionally stable base film of the type specified in the Specification Detail Sheet shall be used.

b. Original camera film shall be clear and sharp in detail and of uniform density. It shall be free from clouds, smoke, haze, light streaks, tears, scratches, and other blemishes or stains. Each sample plot, when photographed, shall be either in full direct sun illumination or in full, but uniform, cloud shadow illumination. No combination of direct sun and cloud shadow illumination, within an individual sample unit, is acceptable. Proper allowances in exposure shall be made for the illumination condition and for the presence of water bodies, deep shadows, or snow fields.

c. To ensure dimensional stability, the film shall not be stretched or otherwise deformed in any way. The film shall at no time be subjected to extreme temperature and humidity changes. Special care shall be taken with the film to store it according to manufacturer's recommendations.

d. All exposed film shall be processed as soon as possible. Partially exposed rolls of completed flight lines may be cut, processed, and delivered for inspection if flying conditions prohibit completion of the roll. During the developing process, special care shall be exercised to ensure proper development, fixing, and washing.

e. All splices shall be accomplished with 3/4-inch pressure-sensitive polyester-base tape. The splices shall be of the butt-joint type with tape placed on both sides of the splice. Particular care shall be given to the alignment of the film when splicing, with care taken to trim all excess binding tape in order that the film be perfectly straight after splicing.

A splice shall not be closer than 5 inches from the image edge of any accepted exposure.

f. All film on a single spool shall bear the same roll number. It shall be thoroughly cleaned and placed on the spool with the emulsion facing the core of the roll. For protection of the project film, a 6-foot length of blank film is required at each end of the roll.

g. Each delivered film can shall be labeled with the roll number and the exposures contained therein. All exposures must be listed on the film can label whether they were used as project coverage or not. Film received without the complete information called for on the film can label shall be returned to the Contractor for correction.

h. The container and spool for each roll of film shall become the property of the Government. Cans of original camera film shall be carefully sealed, labeled, packed, and shipped in substantial boxes to the specified destination. Only polyethylene type film cans are acceptable.

2. Editing and Numbering Aerial Camera Film

a. All lettering shall be positioned as closely as possible to the inside edge of the format of the exposure. The characters used for marking the exposures shall be 3/16-inch high, drafted or stamped with opaque ink to show clearly on all copies of the photographs in the position specified.

b. Each photographic exposure shall be marked in the northwest corner of north-south flights with a numerical annotation which uniquely identifies each frame with regard to sample unit, position within the sample unit, and run number. (The run number will always be "1" unless a sample unit reflight is necessary.) See Attachment 2 for an example of the requisite number code.

c. The most southerly exposure for north-south flights shall be numbered as Exposure Number 1, and any succeeding exposures shall be numbered in an unbroken series throughout the strip. Each strip shall begin with Exposure Number 1 (see Attachment 2).

d. All exposures not used as part of the project imagery (unacceptable quality) shall be marked "Not Used" inside the image area, alongside or immediately below the exposure numbering information. These exposures shall not be removed from the roll except by authority of the Contracting Officer. Exposures extending beyond the sample unit shall be numbered in an unbroken series through the strip.

3. Ownership

a. All original aerial film shall become the property of the Government at the instant of exposure.

b. During the period the film and prints are in the possession of the Contractor, he may make only such use and reproductions as are authorized by the Contracting Officer.

4. Photographic Flight Logs

A photographic flight log shall be maintained on a daily basis and for each roll or segment of film exposed. The logs shall accompany each roll or segment of film delivered. When several days of film exposures are included on a single roll, the logs shall be assembled in the same sequence as on the film. Similarly, when several segments of film are spliced together into a single roll, the logs should be assembled in the same sequence. Each log shall compile the following information:

a. Last names of crew members.

b. Flight date.

c. Aircraft type and registration number.

d. Camera type and serial number.

e. Lens type, serial number, and calibrated focal length.

f. Film type, emulsion number, and expiration date as shown on the manufacturer's packaging.

g. Filter type and number.

h. Roll number - to be completed upon assembly of deliverable film roll.

i. Segment number within a roll - to be completed upon assembly of deliverable film roll.

j. Sample unit number - for each sample unit the following shall be supplied:

(1) Run number - always "1" unless reflights are required.

(2) Beginning and termination frame numbers.

(3) Aircraft heading.

(4) Time of exposure in hours and minutes local time.

(5) Remarks including:

(a) Line complete, or if incomplete, reason for aborting.

(b) Blanks, run-ups, overruns, rejections, and reasons for rejections.

E. Materials to be Delivered

The following materials shall be delivered, prepaid, to destinations designated and shall conform to the requirements stated in these specifications.

1. All original aerial camera film in a sturdy polyethylene film can.

2. All maps supplied must be returned.

3. Photographic flight logs.

F. Aircraft

1. Certification

The aircraft to be used shall have a current and appropriate U.S. Federal Aviation Agency airworthiness certificate and shall be of a type suitable for performing the aerial photography specified.

2. Personnel

Pilot and aerial photographer shall be qualified for the type of work required to satisfy the specifications. Both the pilot and photographer shall be experienced in the performance of precision aerial photography missions.

3. The Contractor shall employ the crews listed in the Bidder's Equipment and Personnel Schedule to obtain the photography required under the contract. No personnel shall be substituted without the consent of the Contracting Officer. The Contracting Officer reserves the right to disapprove any pilot or photographer who is considered incompetent, on the basis of his past records, to perform the work required. Such disapproval shall be given to the Contractor by written notice.

G. Plan of Photography

1. Sample Plot Photography

a. Project and Flight Maps

The following shall be provided to the Contractor:

(1) One set of USGS maps at the largest available scale (either 1:24,000 or 1:62,500) with the center of each 149-foot diameter sample unit annotated thereon.

(2) One set of 1:250,000 scale USGS maps, each encompassing a quadrangle 1° in latitude by 2° in longitude. These maps shall indicate the approximate locations of all sample units and may be used to facilitate mission planning.

b. Flight Lines

(1) Flight lines shall be chosen so as to transect the sample unit in either a north to south or a south to north direction. The flight line for each plot shall consist of a minimum of two (2) overlapping stereo photographs which shall be aligned so that the plot center is within 2.5 inches of the line of flight as viewed on the exposed film. The circular plot shall be photographed in its entirety on at least each of two successive frames.

(2) The sample units shall be marked on the ground with a rubber tire having a white sidewall. This tire will have been staked at the sample unit center.

(3) The flight heights shall be held to limits such that film scales shall be within the range of 1:1,000 to 1:1,500.

(4) Endlap (progressive overlap in line of flight) shall be approximately 60 percent. Any endlap of less than 52 percent or more than 67 percent may be considered sufficient grounds for rejecting any or all photography in a flight strip.

(5) Any series of two or more consecutive exposures crabbed in excess of 10°, as measured from the line of flight, may be rejected.

(6) Tilt in no case may exceed 4°. Relative tilt between any two successive exposures exceeding 6° may be rejected.

c. Photography may be undertaken either when skies are clear or when the entire sample plot is uniformly illuminated by diffuse light (providing there is sufficient illumination to allow a shutter speed fast enough to preclude excessive image motion). Refer to paragraphs C.1.k. and D.1.b. of this specification.

d. Rejected Photographic Coverage

(1) If any photographic coverage submitted for inspection does not conform to the

requirements of this contract, the Government shall have the right to reject such coverage, or to require its reflight or correction. Since the vegetation development stage is so critical and reflights may not be possible it shall be the Government's option to either require a reflight or to decrease payment for those photographs which do not meet technical specifications.

(2) All reflight photography shall be flown using the same camera system as used for the original photography.

(3) Reflight film shall be marked with the same sample unit number as that which it replaces, followed by the numeral "2" (i.e., Run No. 2) for the first reflight, and "3", "4", etc. for succeeding reflights (see Attachment 2).

H. Permits and Clearances

1. Acquisition

a. The Contractor shall, without additional expense to the Government, obtain all Federal and local licenses, permits, and clearances necessary for the performance of the contract. (Where a project includes a military installation, the Contractor may be required to visit the installation in order to obtain clearance from the military commander.)

b. The Contractor shall be required to observe all Government security regulations during the performance of the contract.

c. The Contracting Officer will render assistance in obtaining required security clearances.

2. Restricted Areas

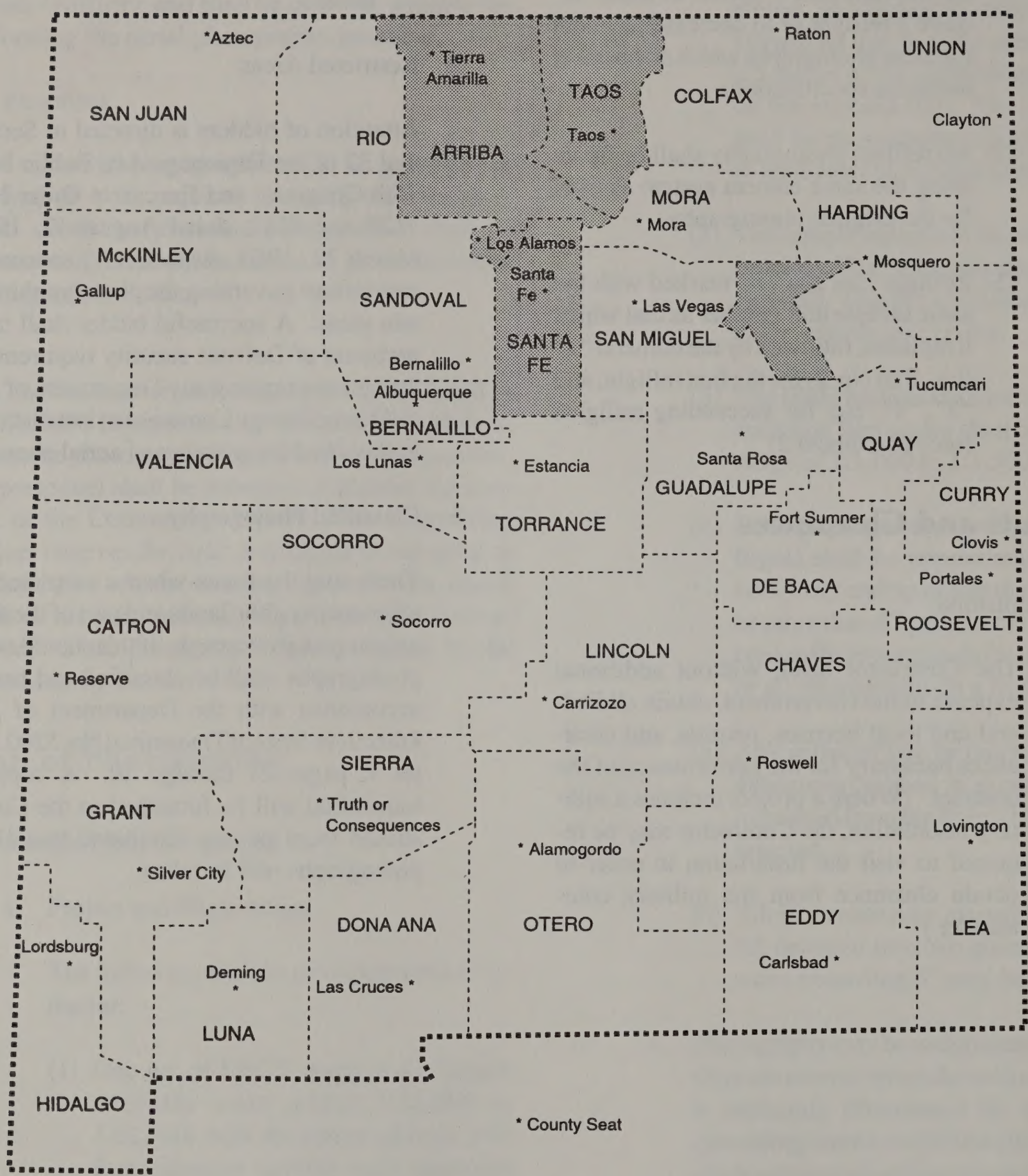
Attention of bidders is directed to Sections 31 and 32 of the Espionage Act, Public Law 418, 75th Congress; and Executive Order Numbers 7138 and 8381, dated August 12, 1935, and March 22, 1950, respectively, concerning the restrictions governing the photographing of certain areas. A successful bidder shall meet Department of Defense security requirements before photographing any Department of Defense or Atomic Energy Commission installation which is classified for purposes of aerial photography.

3. Classified Photography

There may be times when a restricted area is adjacent to public lands and part of the area may appear on a photograph. If this should occur, the photographs shall be classified and handled in accordance with the Department of Defense Directives System Transmittal No. 5200.1, Chapter 9, pages 27 through 30. A copy of the transmittal will be furnished to the Contractor should there be any likelihood that classified photographs will be taken.

Attachment No. 1

The New Mexico Project Area

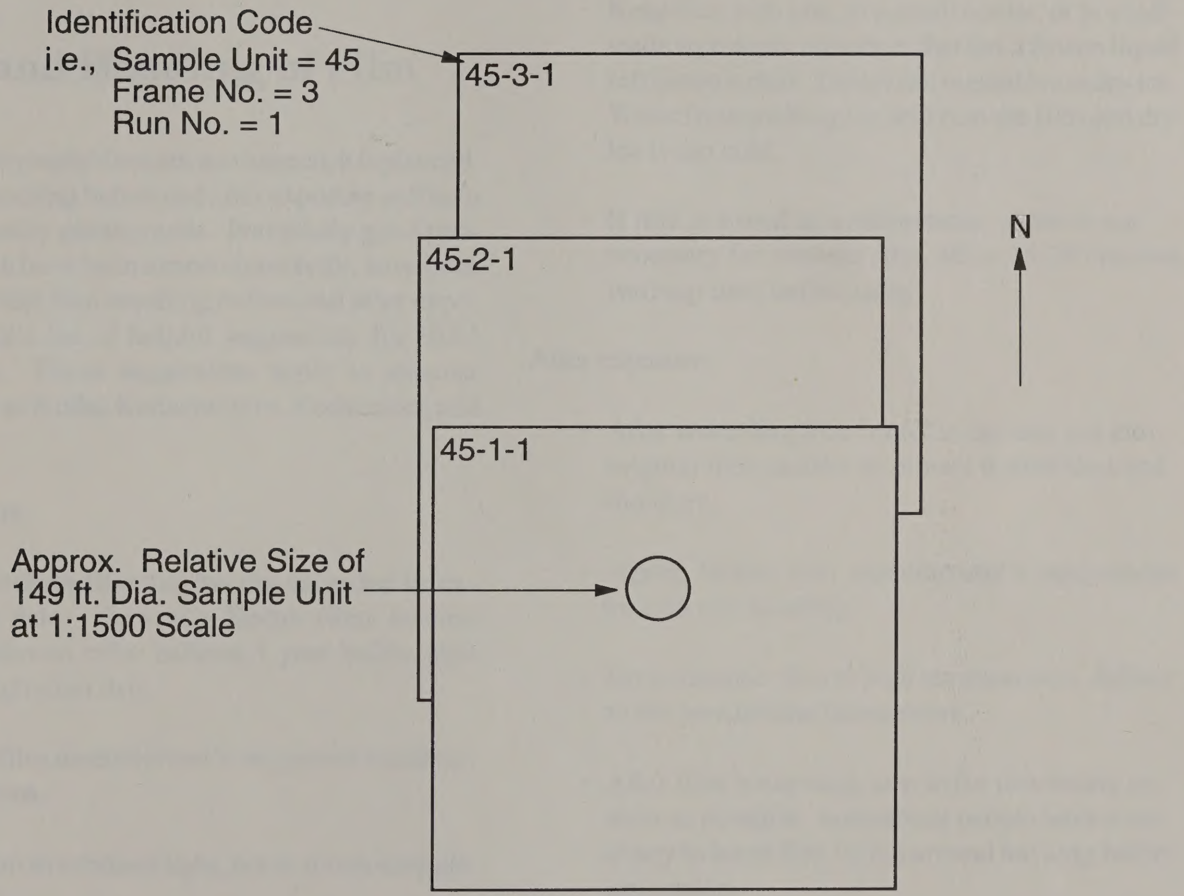


Outline Map of New Mexico and its County Boundaries

Areas highlighted by shading comprise the project area and are the locations to which sample unit aerial photo sites may randomly be allocated.

Attachment No. 2

Illustration Showing Correct Procedure for Numbering Flight Lines and Exposures



Appendix II
Suggestions for the Care and Handling of Photographic Films

Because photographs, either ground or aerial, can document conditions in both short- and long-term monitoring, the range specialist will often find it useful to take photographs each time a trend transect or plot is visited. Various films, cameras, and formats may be used. Prints and slides from 35-mm film with a normal or wide angle lens may be useful for trend assessment. With this in mind, the following suggestions for film handling are provided.

Care and Handling of Film

Good photography does not just happen, it is planned. Careful film handling before and after exposure will help ensure high quality photographs. Potentially good photographs, which have been exposed correctly, have been ruined by careless film handling before and after exposure. Below is a list of helpful suggestions for BLM photographers. These suggestions apply to amateur color film such as Kodak Kodachromes, Kodacolors, and Ektachromes.

Before exposure:

- Only purchase film that has not exceeded its expiration date. Generally Kodak films achieve their optimum color balance 1 year before their listed expiration date.
- Follow film manufacturer's suggested handling instructions.
- Load film in subdued light, not in direct sunlight.
- Protect film or loaded cameras from temperatures that are 100° F or higher.
- Do not leave film in the glove box.
- Do not leave film on the dashboard.
- Do not leave film in a closed vehicle, especially in the summer.
- Keep film with you, in a small cooler, or in a self-made styrofoam container that has a frozen liquid refrigerator pack. Do not use regular ice or dry ice. Water from melting ice will ruin the film and dry ice is too cold.
- If film is stored in a refrigerator, which is not necessary for amateur film, allow 15-20 minutes warmup time before using.

After exposure:

- After unloading film from the camera, put into original film canister to protect it from dust and moisture.
- Again, follow film manufacturer's suggestions for care and handling.
- Do not subject film to high temperatures. Adhere to the precautions listed above.
- After film is exposed, turn in for processing as soon as possible. Sometimes people have a ten dency to leave film laying around too long before processing.

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